

J. Downing
The Coast of Puget Sound
Puget Sound Books

Figure 2.1 Monthly runoff of the Deschutes and Snohomish rivers. Snow accumulation in the Snohomish watershed results in a winter minimum. Deschutes River runoff coincides with precipitation because its watershed does not receive much snow.

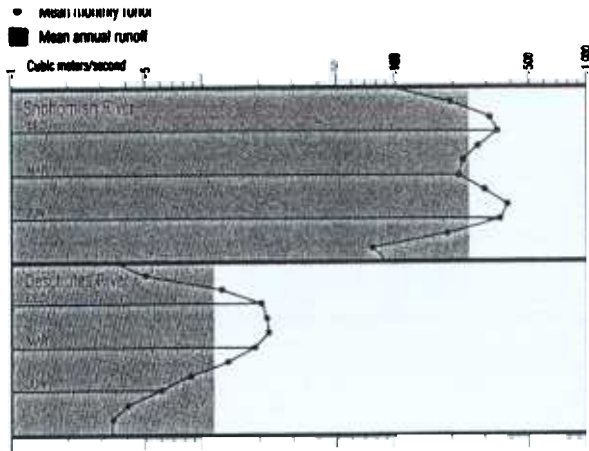


Figure 2.2 Circulation and paths of sediment transport near a river mouth. Onshore flow at the bottom (solid arrows) traps sediment near the river mouth.

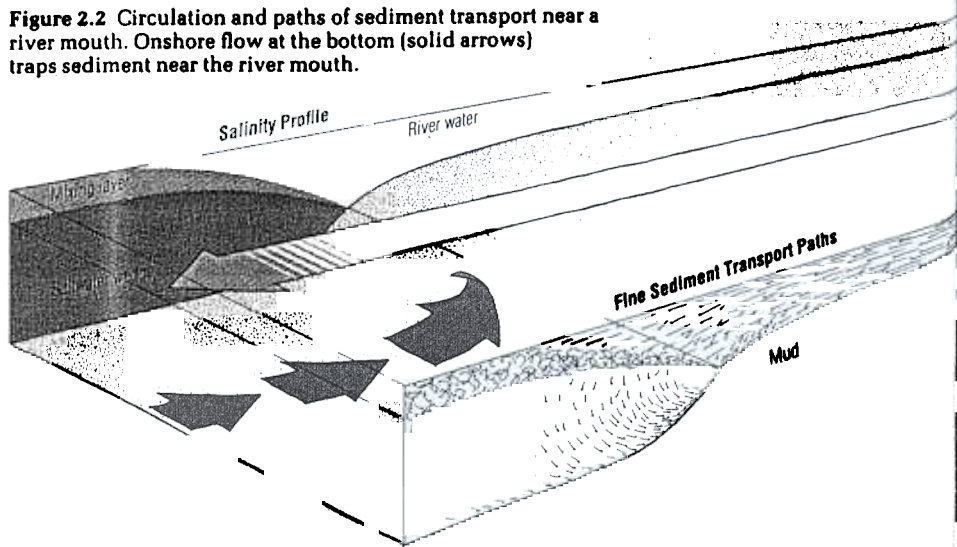


Figure 2.3 Tidal mud flat and a small delta in Oakland Bay, Mason County.



River Deltas

Rivers and streams rate well below the glaciers as suppliers of sediments for building coastal landforms in Puget Sound, and yet their imprints on shore evolution in the region have been major. The most remarkable features are the large deltas that have formed at the mouths of major river valleys since the last glaciation. These deltas developed where the rivers delivered a sufficiently large supply of sediment to fill up their lower valleys as the sea rose to its present level. Major river deltas have advanced substantial distances into the deep basins of Puget Sound, creating large areas of alluvium. These lands are agriculturally rich and also highly valued for industrial and commercial uses.

The currents and patterns of sedimentation at river mouths which give rise to these alluvial deposits are here described in general terms. In addition, several of the major river deltas are discussed in greater detail because of their unique geologic history or relevance to development of the coastal zone.

Currents and Sediments Near Rivers

Delta growth has a seasonal nature that is linked to the variation of freshwater discharge during the year. This variation is illustrated in Figure 2.1 which shows the mean monthly discharge of the Snohomish and Deschutes rivers for a 30-year period. Similar variation in discharge occurs during the year in most of the larger rivers that receive both rainwater and snowmelt from the mountains. The relative height of the winter and spring discharge peaks varies from river to river depending on the proportion of the drainage area that is covered with snow. Rivers draining mountainous areas have peak discharges during the spring thaw, whereas those draining exclusively lowland areas have peak flows during the rainy periods of late fall and early winter.

Fresh water discharged from rivers and streams drives a system of currents which moves the sediment that forms deltas at river mouths. In sheltered bays where waves and tidal currents do not mix the fresh runoff with the underlying denser salt water, stratification of the water column develops and a slow landward flow of salt water near the bottom occurs (Fig. 2.2). This circulation pattern provides a return path for fine sediment as it settles out of the river plume. Fine sediment is

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trapped near river mouths in this manner and forms the mud shoals and tidal flats that exist at the heads of most protected bays (Fig. 2.3). Sediment deposition rates can be very high in these areas and are a critical factor to be considered in the design of port facilities and navigation channels because costly maintenance dredging may be necessary.

During periods of high discharge, currents are sufficiently strong to transport sand and gravel on the deltas. Transport rates of sand and gravel are particularly high at the lower stages of the tide. At these times freshwater flow is largely restricted to the distributary channels and is in contact with the channel bed. During high tide the fast freshwater current is displaced from the channels by a wedge of denser salt water and very little material is transported along the channel beds.

Wetlands Accretion

The seaward progression of the shoreline across the delta with time creates new wetlands by a process requiring joint contributions by biological and physical agents. A large fraction of alluvial soil is fine-grained mineral material transported to the river delta by flood waters and tidal currents. In order for this material to settle out of suspension, current speeds must be very low, usually less than 0.20 meters per second (0.4 knots). Tidal flows infiltrate the wetlands through a network of small channels and disperse suspended sediment among the marsh vegetation. Marshes are also inundated during winter and spring floods when sediment-laden river water overflows the distributary channel levees. Once sediment-laden waters flood the marshes, resistance of the vegetation slows the water, and fine sediment can then settle out among the plants. Since the current speed required to resuspend it is much greater than the current speed when deposition occurred, it is trapped there and the soil level builds upward as additional fine mineral material is added. Figure 2.4 shows sediment mounds in salt marsh vegetation that have developed by this process.

Marsh Plants

A very special plant community has adapted to the frequent shifting of the sand and gravel substrate by wind and waves and to the wide fluctuations in the salinity near the delta shore. The outer perimeter beach is the main line of defense that protects unconsolidated deposits in the wetlands from wave attack. At high tide most of the wave energy that reaches the delta is dissipated there. Just landward of the berm the substrate remains relatively undisturbed for periods of a year or more between major storms. Small isolated plant communities spring up in bunches among the drift logs and other beach debris. Yellow abronia, silver beachweed, European beachgrass, and American beachgrass are members of the pioneer beach plant assemblage commonly found in



Figure 2.4 Mud deposits among salt marsh vegetation, an example of geological and biological processes building wetlands together.



Figure 2.5 Beach grass, morning glory, knotweed and other shore vegetation help to stabilize berms and backshore areas and protect them from waves and wind.

Puget Sound. These stout plants provide sheltered environments that trap windblown sand which over the years builds up a beach ridge that may reach a few meters above mean higher high water (Fig. 2.5).

On top of and behind the beach ridge the mound-building plants merge into denser vegetation that tolerates windblown sand but not extensive erosion of the substrate. This community includes seashore bluegrass, large-headed sedge, gray beach pea, beach morning glory, beach knotweed, American beachgrass, American sea rocket, and beach pea. The ground cover of these plants, if dense and uniform, protects the beach ridge from wind erosion quite well. Plant roots intermesh in the sand and gravel and form a tight matrix that binds material together and anchors it to the beach ridge. The stems and foliage shelter the ridge surface from the direct attack by wind. Beach ridges built up in this manner have been augmented by man-made levees on most large river deltas.

The Major Contributors

The twelve largest rivers in the Puget lowland (not including the Fraser River) discharge about 3.2 million metric tons (3.5 million short tons) of sediment into the Puget Sound annually. The approximate volume of this sediment is 1.8 million cubic meters (2.4 million cubic yards) and were it all to be deposited on the bottom of Puget Sound (this could never happen) the estuary present today would be filled in about 83,000 years. On the average, 90 percent of a river's sediment load is suspended fine-grained material; the rest is coarser bedload, mostly sand.

Figure 2.6 illustrates the runoff and sediment discharge of major rivers in the Puget lowland. Mean annual and average monthly runoff values are based on river gauging over the 30-year period from 1931 to 1960 and accurately represent the hydrology of these rivers. The sediment discharge data, however, were acquired during 1- to 2-year periods between 1964 and 1966 and are useful only for comparing sediment loads on a relative basis. It is not known if sediment loads during these years were representative of the long-term averages for any of these rivers.

The five rivers in the northern half of the Puget lowland, the Elwha, Nooksack, Skagit, Stillaguamish, and Snohomish, contribute 70 percent of the fresh water discharged into Washington's intracoastal waters. Four of these rivers, the Nooksack, Skagit, Stillaguamish, and Snohomish, introduce more than 69 percent of the fluvial sediment to the same area. It is not surprising, therefore, that the largest deltas are located in the northern lowland. The group of rivers including the Nooksack, Dungeness, Elwha, Skagit, Snohomish, Puyallup, and Nisqually has a similar annual cycle of runoff. Early fall runoff is low following the dry summer months; sediment discharge is at a minimum at this time as well. Runoff and sediment loads increase to a maximum during the early winter months when there are frequent storms. The heavy precipitation from winter storms falls on ground unprotected by snow at the lower elevations so that soil erosion produces large suspended loads in these rivers. During this period, flooding of bottomlands occurs and high velocity currents move sediment, accumulated in the river channels during lower water stages, onto the delta platform.

As the pattern of monthly runoff suggests, the deltas of these rivers receive a large fraction of their annual sediment input in early winter and late spring. A dip in runoff follows the winter peak because much of the precipitation is stored temporarily in the snow pack of the high catchment basins. High precipitation continues during the spring and rising air temperatures in the mountains melt the snow pack, releasing large volumes of meltwater to the drainage system. The combined runoff from meltwater and seasonally high precipitation produces a spring

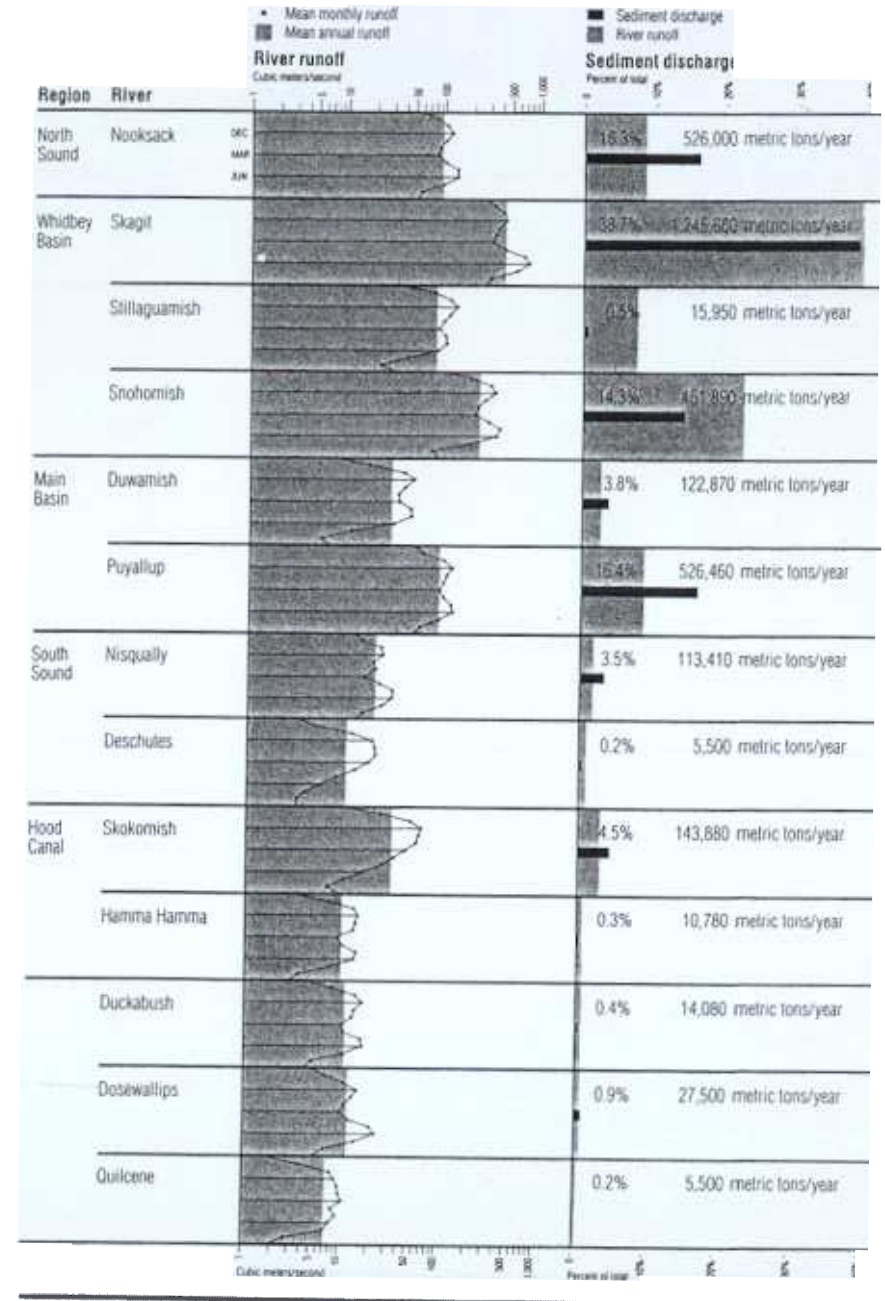


Figure 2.6 River runoff (left) and sediment discharge (right) of major rivers in Puget Sound. Proportions of total sediment discharge (3.22 metric tons/year) contributed by individual rivers is indicated by percentages. Note that the sediment loads of the Puyallup and Nooksack rivers are large in proportion to runoff but the Stillaguamish and Snohomish rivers are relatively clear.

peak that is higher than the winter peak in most years. Suspended loads in rivers during spring floods are not as large as one would expect from the high runoff since the ground is protected from the direct impact of rain by a layer of snow and soil erosion at higher elevations is less severe.

The watersheds of the Green and Deschutes rivers are at low elevations and very little precipitation is stored in a snow pack during the rainy winter months. Consequently, the runoff and sediment discharge follow the same seasonal trends as the regional precipitation. Seasonal variation in the Stillaguamish runoff is a hybrid of the two above patterns; the winter peak is larger than the spring peak. A lower yet significant proportion of the catchment basin is at high altitudes; thus the large winter maximum in precipitation predominates the runoff curve.

Pristine Deltas

The Nisqually and Nooksack deltas are the most studied examples of sedimentation at river mouths in Puget Sound. In comparison with other large deltas in the region, only minor aspects of them have been modified by man, so they provide good examples of natural sedimentary features.

Nisqually delta Figure 2.7 illustrates the major parts of the Nisqually in cross section. The inner delta extends landward of mean high water and consists of low-lying wetlands dissected by many shallow tidal and distributary channels. The freshwater discharge and sediment load of the river pass through a network of distributary channels on route to the Sound. Between these distributaries small marshy islands form. The outer delta is intertidal and lacks the terrestrial marsh vegetation of the inner delta. Like the inner delta, the intertidal surface is flat and is divided by a complex pattern of tidal channels. At the outer edge, the slope of the delta front steepens and dips offshore into deeper water. The horizontal sedimentary beds that make up the delta platform are called topset beds. These consist of mud deposits rich in organic material that accumulate in the inner delta wetlands, sand deposits in tidal and distributary channels, and other intertidal sediments of finer texture. The delta front consists of steeper foreset beds which have accreted seaward over the previously existing bottom sediment. Foreset and bottomset beds usually consist of mud and fine sand. As the delta front advances out into deeper water with time, more and more sediment is required to produce new surface area on the delta platform. Therefore the rate of seaward advance of the shoreline as the delta grows in volume will decline with a constant supply of river sediment.

The river is the major supplier of sediments to the Nisqually delta. It discharges about 0.11 million metric tons (0.12 million short tons) of

material into Nisqually Reach annually and ranks fourth as a sediment source among the major rivers. The sand and fine material carried by the river move through the inner delta wetlands in the large distributaries. Because the sediment transport is confined to channels, very little of it accumulates on the inner delta. When the river's sediment load reaches the intertidal delta, the sediment dispersal pattern is determined by the height of the tide and the intensity of wave and current activity at the distributary mouths. At low tide the suspended load and bedload are transported across the intertidal delta in shallow channels that are extensions of the main distributaries. At high tide these channels are submerged and the plume of suspended sediment is moved about by tidal and nearshore currents, and the transport of sand and coarser material on the bed ceases. Longshore transport is another process that carries sediment to the Nisqually delta. Compared with the river sediment load, the longshore contributions of sediment are of minor importance, but they are vital to the stability of the beaches on other more exposed deltas. Longshore transport provides the coarse material to form berms and beach ridges that can protect the marshes and wetlands from wave attack.

Sediment from the Nisqually River and longshore sources can leave the delta along the coast or across the delta front. Some of the material transported along the shore remains in the nearshore zone and is incorporated directly into the delta transport system. Bedload material, primarily sand from the river, however, follows a more complex route before it leaves the delta. At high tide, the bedload accumulates in bars or shoals near the distributary mouths. These bars are eroded by the river when it reoccupies distributary channels on the falling tide. Some of this material is dispersed on the intertidal platform by waves and tidal currents; the rest is transported in the distributary channels to the delta front. Some of the sand dispersed from the distributary channels is moved onshore by waves and accumulates on the beach. This sand then becomes part of the beach and moves along the delta shoreline and down the coast.

The suspended load of the Nisqually River can escape the delta via more direct routes. At low tide it is injected into the tidal flow at the delta front as a muddy plume which is dispersed from the delta during subsequent tidal cycles. During higher tidal phases the plume of suspended material disperses across the intertidal delta because the denser saline water displaces the fresh water above its channel bed. Part of the material settles to the bed by the process illustrated in Figure 2.2; the rest is carried offshore by the falling tide. Because of its moderate wave climate, the Nisqually delta is an excellent example of deltaic sedimentation controlled almost entirely by tidal and fluvial currents.

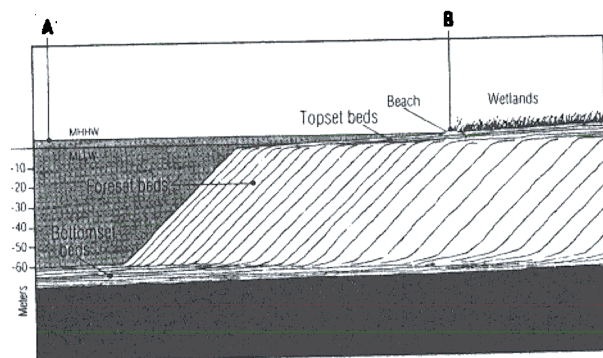


Figure 2.7 Simplified cross section of the Nisqually delta illustrating its major parts. Points A and B are located on Figure 2.8.

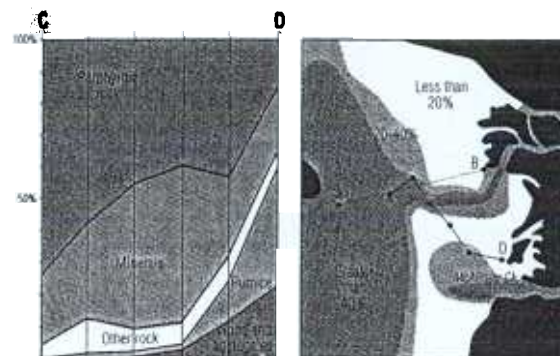


Figure 2.8 Distribution and composition of sand in Nisqually delta sediments.

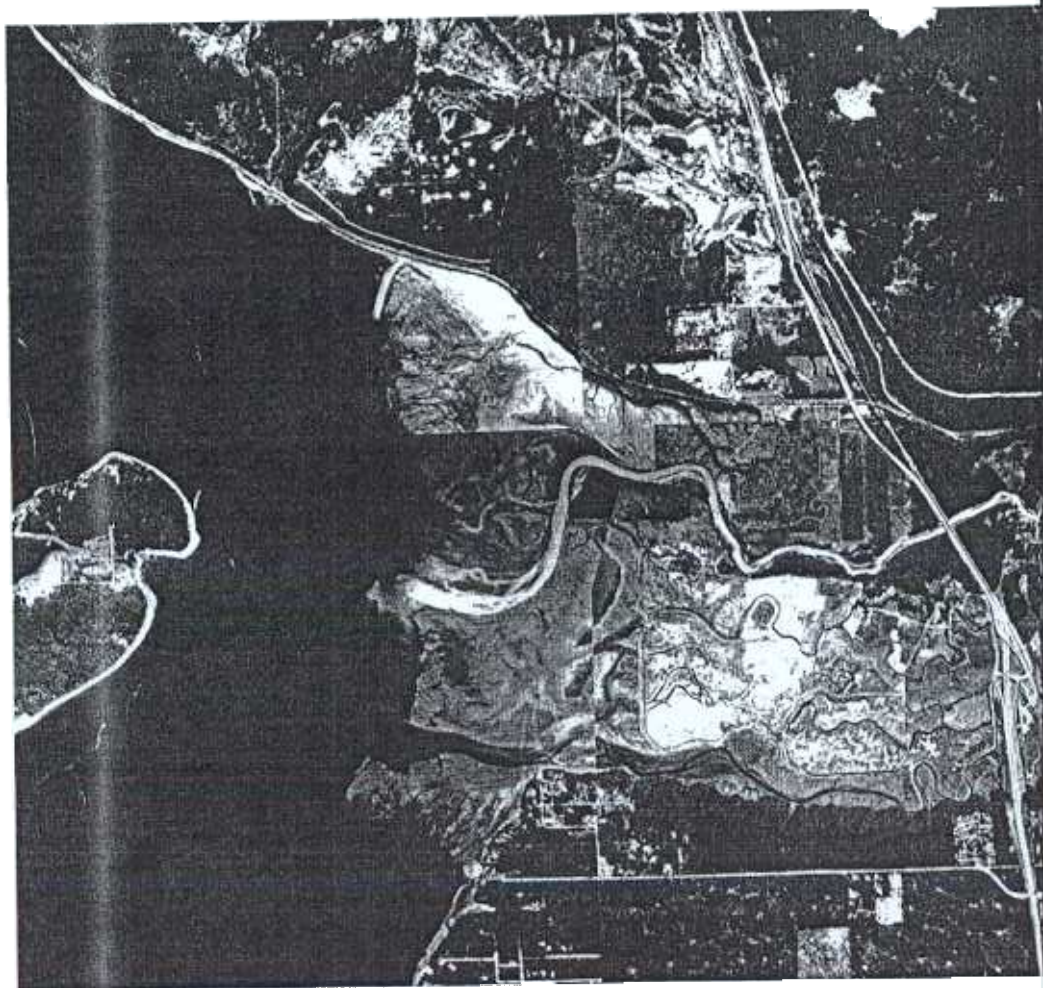


Photo mosaic of the Nisqually delta at low tide. The main distributary appears white because of the glacial rock flour suspended in the river. (Photo courtesy Corps of Engineers.)

Since the last glaciation, the Nisqually has filled an inlet with sediment and advanced into the basin at about 50 meters (160 feet) per century. The constriction of the channel connecting the south and central basins of Puget Sound by delta sediment increased the tidal current speeds there until an equilibrium between sediment deposition and dispersal by currents was eventually reached. During the final phase of delta formation, these strong tidal flows carried most of the sediment away from the center of the delta. More extensive outward growth occurred along the east and west margins where tidal flows were weaker. The unique crescent shape of the outer Nisqually delta reflects these final events in its development.

The processes that move river sediment through the nearshore environment are evident in composition, particle size, and distribution of sediments on the delta surface. Before dams were built on the Nisqually River, much of the bedload carried to the delta derived from volcanic rocks exposed at the river's source near Mt. Rainier. Evidence of a volcanic origin is quite apparent in the intertidal and marsh sediments where a large portion of the coarse material consists of volcanic rock fragments. This dense material resists erosion and forms deposits on the outer delta where tidal currents are vigorous. Pumice, a low-density volcanic material, is abundant in the silty sediments on the tidal flats near shore where currents are weak. Figure 2.8 illustrates the variation in abundance of these and other sediments across the delta.

Sand is abundant in the main distributary, on the delta front, and in the tidal channel at the mouth of McAllister Creek (Fig. 2.8). The high percentage of sand in these deposits indicates that the sediments in these areas are moved primarily as bedload. As the tidal and distributary channels meander across the intertidal delta, they spread some of their sand load in finger-like deposits that extend out from the shoreline. The tidal flats to the east and west of the main distributary are covered with finer material that contains up to 90 percent silt. Silt deposition occurs during river floods and high tides when there is little

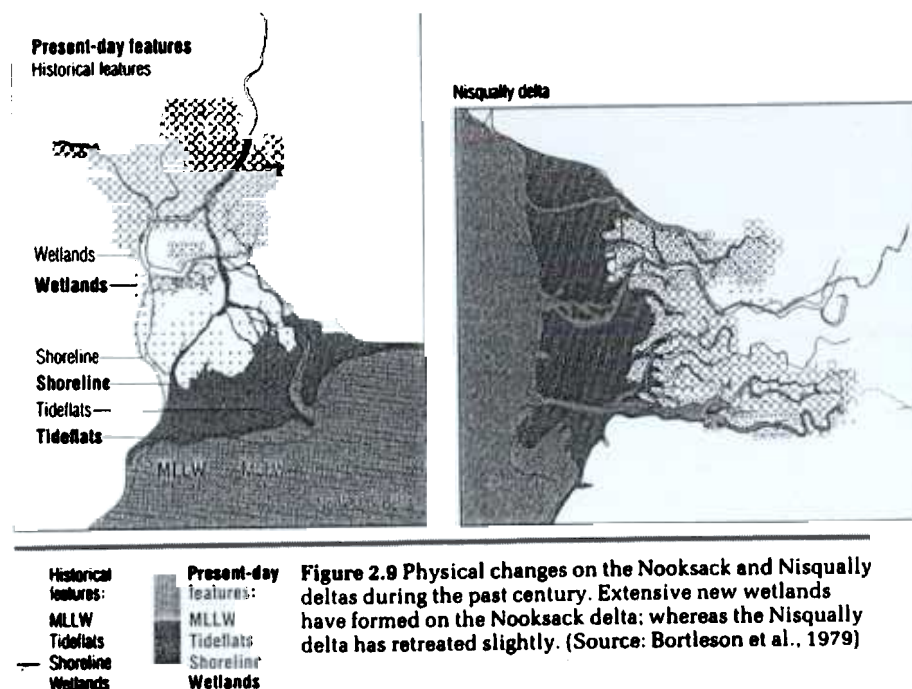


Figure 2.9 Physical changes on the Nooksack and Nisqually deltas during the past century. Extensive new wetlands have formed on the Nooksack delta; whereas the Nisqually delta has retreated slightly. (Source: Bortleson et al., 1979)

wave activity. Some sand is resuspended by storm waves and is carried away from the channels; small quantities of sand transported in this way are intermixed with the silts on the tidal flats.

Winter and late spring floods are vital to the Nisqually wetlands because they supply the marshes with the fine sediment necessary for continued growth. Although the shoreline at the mouth of the Nisqually has been quite stable since 1878, Figure 2.9 shows that small losses of wetlands area, about 1.6 square kilometers (0.62 square miles), have occurred around the marshy islands near the main distributary. These losses may have resulted from natural shifts in the channel location that have occurred in the past 100 years.

More pronounced changes have occurred at the delta front since 1878. The intertidal delta has retreated 75 to 300 meters (250–1,000 feet) and it appears that the rate of sediment supply to the delta front is not in balance with the rate of removal by tidal currents. Although the cause of the imbalance is not known with certainty, a reduction in the supply of fluvial sediment is the most plausible explanation.

Nooksack delta This delta has undergone the most dramatic growth of any coastal sedimentary feature in the Puget Sound region in recent times. Its growth is a good example of an imbalance between marine processes, waves, and nearshore currents that remove sediment from the delta and the supply of river sediment to the delta. Wetlands have advanced seaward over 1.5 kilometers (0.93 miles) on the intertidal platform, producing 3.0 square kilometers (1.16 square miles) of

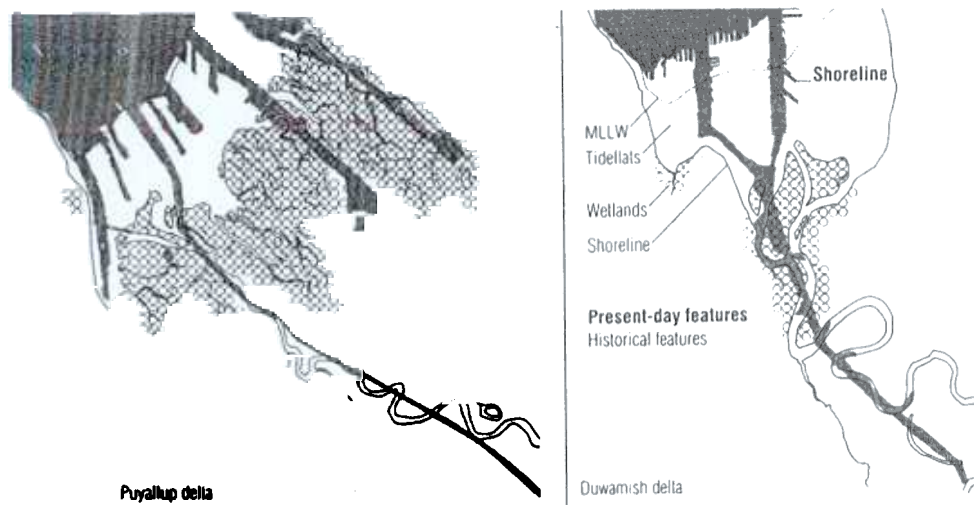
new bottomland. The area of the intertidal delta has decreased as portions of it have evolved into subaerial wetlands. The eastern corner, however, is encroaching on Bellingham Bay, creating costly shoaling problems in some navigation channels. These historical trends in the development of the Nooksack delta are illustrated in Figure 2.9. Between 1888 and 1972, the main river channel has cut across a large oxbow. Several small interdistributary islands at the former river mouth have coalesced into a much larger one, occupying the western half of the river valley, and islands have formed in the eastern half of the valley as well. Just west of Marrietta, longshore movement of sand from the river has formed a spit 0.3 kilometers (0.19 miles) long that is growing across the mouth of the east distributary channel. What was an intertidal bay fewer than 100 years ago now is a group of islands that has extended the coastline out to the mouth of the river valley.

The intertidal platform of the Nooksack delta is covered with a layer of medium sand that contains about 12 percent silt and clay. Numerous shallow distributary channels 1.2 to 1.5 meters (4–5 feet) deep have cut across the delta platform sand. At low tide the bedload from the river moves seaward in these channels, but during high tide wave and tidal currents disperse the channel sands evenly over the delta platform. The two-step process by which river sand is distributed over the intertidal delta is probably not continuous, rather it requires storms to produce wind waves large enough to move the sand away from the channels. Small waves during calm weather move these sands only in the breaker zone. Part of the river-derived sand on the inner delta is transported onshore by waves and nourishes the beaches along the seaward shores of the interdistributary islands. Continued growth of these beaches with new material from the delta platform is important to the growth of the wetlands here.

Very little river silt and clay are deposited permanently on the intertidal delta. Waves and tidal currents are sufficiently vigorous to keep this material in suspension and carry it to the deeper water seaward of the delta front. Deposits of this material 1.5 to 6.1 meters (4.9–20 feet) thick have accumulated in the northern half of Bellingham Bay in post-glacial time.

Developed Deltas

Duwamish delta The Duwamish delta is the best example in the Puget Sound region of a natural delta completely altered by man. Without historical survey data, it is nearly impossible to recognize any of the delta's natural features. Prior to channel straightening, the Duwamish River meandered widely over a sinuous course on the flood plain now the site of Boeing Field and the south Seattle industrial com-



Historical features:
 MLLW
 Tidelands
 Shoreline
 Wetlands

Present-day features:
 MLLW
 Tidelands
 Shoreline
 Wetlands

Figure 2.10 Deltas like the Puyallup and Duwamish in urban and industrial areas have been altered drastically by man. Former river channels, wetlands, and intertidal areas are no longer recognizable. (Source: Bortleson et al., 1979)

plex (Fig. 2.10). Two small inlets, remnants of old river meanders, still exist in the Georgetown district of Seattle. In 1854, the river flowed into Elliott Bay through a group of four interdistributary islands. These wetlands and nearly all of the intertidal delta platform have been filled and developed by the City of Seattle, representing a loss of about 10.8 square kilometers (4.2 square miles). Although few would dispute the long-term benefits of this commitment of resources, there remain certain costs to be paid for these benefits. Ground instability of hydraulically filled areas and degraded water quality are but two examples. Subsidence along the Duwamish waterway occurred during the 1949 and 1965 earthquakes and other ground failures have occurred more recently on areas improperly and unsafely filled.

Puyallup delta Like the former Duwamish delta, the natural Puyallup delta (Fig. 2.10) is now unrecognizable as a result of extensive man-made alterations. The Port of Tacoma has extended large piers across the intertidal platform to the delta front and across the width of Commencement Bay's southeast shore. The Hylebo, Port Industrial, and Puyallup waterways have been dredged through former wetlands. A total commitment of 17.3 square kilometers (6.7 square miles) of delta surface was made in the past century to develop Tacoma's port and industrial facilities of which 10 square kilometers (6.1 square miles) were formerly wetlands.

The Puyallup River rates second jointly with the Nooksack as a sediment source in the Puget lowland where it discharges 0.5 million

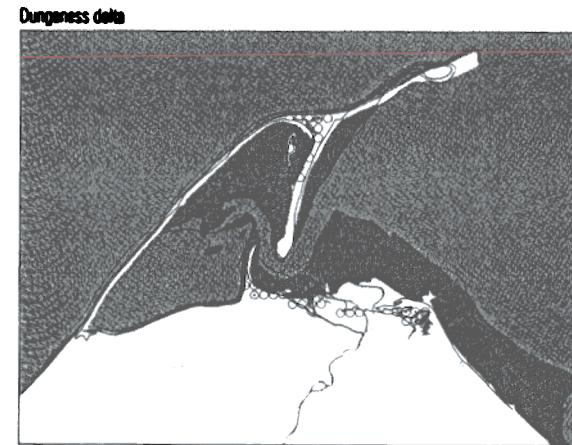


Figure 2.11 New tideflats and wetlands have formed on the Dungeness delta, and Dungeness Spit has grown over the past century. The spit has grown 500 meters since 1855. (Source: Bortleson et al., 1979)

metric tons (0.6 short tons) of sediment into Commencement Bay annually. Commencement Bay is an ideal location for a port in many respects because the bay is sheltered from direct wave attack and it is near large population and industrial centers. Since it was once a natural delta system, however, sedimentation is a major problem in the artificially deepened navigation channels and waterways. Tidal currents in the bay are weak, causing much of the river's sediment load to accumulate in the navigation channels where it must be removed by dredging. The annual cost of channel maintenance offsets some of the cost benefits arising from the port facilities' geographical location.

High Energy Deltas

Dungeness delta The Dungeness River ranks last both in terms of mean annual runoff and estimated sediment discharge (90 metric tons [100 short tons] per year). Nonetheless, the recent history of sedimentation on its delta has been an eventful one. The 1855 survey of the delta revealed that a complex of spits had formed east of the present-day river mouth. These spits have grown across the delta front in a westerly direction substantially increasing the wetlands at the river mouth (Fig. 2.11). The river mouth shifted about 600 meters (1,970 feet) to the east during the same period and eroded a small spit in the process. Duck Spit has extended at the rate of about 5 meters (16 feet) per year into Dungeness Bay. The outer edge of the intertidal platform is now located up to 0.50 kilometers (0.31 miles) farther offshore than in 1855.

These recent depositional events indicate that the fluvial sediment input to the delta has exceeded the rate of sediment removal by dispersal processes. Waves and tidal currents, nevertheless, have caused significant redistribution of fluvial sediment on the delta, and the shape of the intertidal and wetlands areas near the river mouth shows signs of substantial reworking. For example, tidal currents have cut an S-shaped channel across the western portion of the tidal flats. This channel is maintained by the scouring action of water flow in and out of Dungeness Bay. Wind waves approaching from the northeast have built a spit that deflects the main distributary about 0.40 kilometers (1,300 feet) to the west. The future of the Dungeness delta depends critically on the continued existence of Dungeness Spit as a natural wave barrier. The spit has grown steadily over the past 120 years at the rate of 4.5 meters (15 feet) per year and, unlike Ediz Hook, it appears to be a very stable feature. Consequently, continued seaward growth of the Dungeness delta is expected.

Elwha delta The Elwha River flows into the deep and exposed waters of the Strait of Juan de Fuca. Its flood plain fills a shallow valley in the northern foothills of the Olympics. The delta is lobe-shaped, symmetrical, and lacks the interdistributary islands and extensive wetlands that fringe other deltas formed in less exposed waterways. At the present time, the Elwha River supplies very little sediment to Puget Sound. There is evidence, however, that the Elwha River was a very prominent sediment source in the recent geologic past.

Soon after the glaciers receded, the gradient of the river channel was steep, cutting across extensive deposits of unconsolidated glacial material that had formed between the Olympic foothills and the ice-blocked Strait of Juan de Fuca. The glacial material was easily eroded and the river discharged large quantities of it into the Strait, forming an extensive delta. Various stages in the growth of this delta are illustrated in Figure 2.12. The area of the ancestral delta during its early growth was at least five times that of the present one. Moreover, it appears that the prevailing direction of wave approach and longshore transport was from west to east as it is today. This is indicated by the more extensive sedimentation that occurred to the east of the river mouth and by the short east-trending spits that developed on the downdrift flank of the delta. Rising sea level and concurrent shore bluff erosion gradually shifted the location of these spits eastward and onshore. Eventually a single large spit developed at the site of Ediz Hook and evolved into the feature seen today. As sea level rose from 33 meters (108 feet) to the present level, the gradient of the river decreased and the supply of glacial sediment along its lower reaches diminished, causing a reduction in the sediment discharge to the delta. Wave activity during this period probably remained nearly constant and at some point began removing

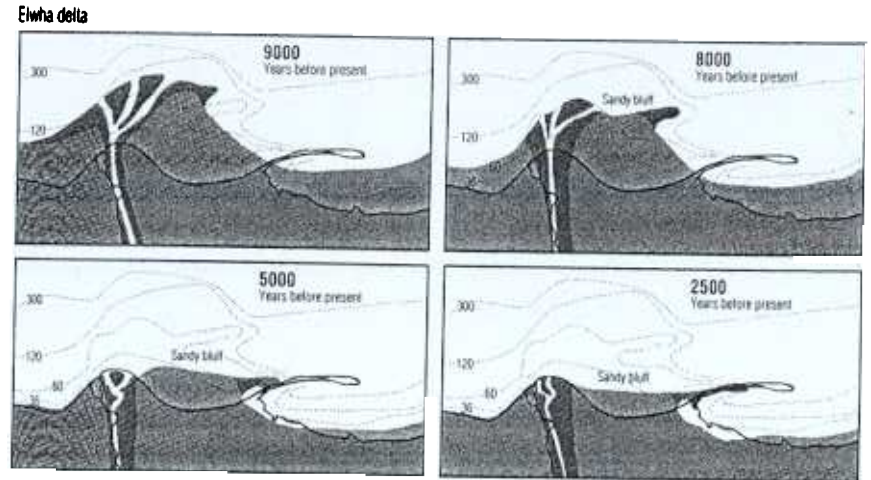


Figure 2.12 Geological history of the Elwha delta and Ediz Hook over the past 9,000 years. Rising sea level and wave erosion have diminished the delta's size and moved much of its original sediment to Ediz Hook.

fluvial sediment from the delta front at about the same rate it was discharged there. The equilibrium between sediment supply and dispersal resulted in the smaller delta that exists today. The evolution of the Elwha delta is one of the better known examples of how the interaction among changing sea level, nearshore, and fluvial processes can influence the sedimentary features along the Puget Sound coast.

The sediment budget of the Elwha delta is delicately balanced at the present time. Since 1910, the lower Elwha Dam has reduced the bedload of the Elwha River by 90 percent. The Glynes Canyon Dam, completed in 1926, has further aggravated the sediment supply problem. The current flood control procedure consists of releasing water in surges to the lower Elwha channel when the reservoir levels become critically high. These surges often occur during high water and serious flooding of the outer delta results. The procedure causes other, more permanent, damage as well. High runoff erodes the river bed and levee deposits, transporting the material to the intertidal delta. Since the supply of coarse material from the upper river is cut off by the dams, sediment is not redeposited in bottomlands between floods and the loss is a permanent one.

Accretion of wetlands on the Elwha proceeds slowly because very little sediment is supplied to the marshes. In other river systems, flooding of the interdistributary marshes occurs more frequently and less catastrophically than on the Elwha. Periodic inundation of wetlands with sediment-laden river and tidal waters provides the mineral material necessary to sustain the marsh plant community and to build up

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the soil profile. Tidal flooding of the Elwha delta is infrequent because of the high beach ridges that fringe the outer marshes. As a consequence of the short supply of fine-grained suspended sediment, the outer marshes have not developed above the groundwater table in many places on the delta and they are perennially swampy.

In view of the restricted sediment supply, it is surprising that the shore of the Elwha delta can survive the rigorous wave climate in the Strait of Juan de Fuca. The stability of the shore at the present time is due in part to the location of the delta at the end of the Freshwater Bay transport cell. Longshore transport of gravel and cobbles from the eroding bluffs provides continuous nourishment for the beach ridge which is the primary protection from storm wave activity. The beach ridges have a natural capacity to absorb and dissipate wave energy, due to their porosity and rough surface. Minor breaches of the beach ridge occur from time to time; and were the sediment supply from Freshwater Bay to be interrupted, major erosion problems would be experienced.